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S U P E R C H A R G E R S

By Pierre Léglise

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In aviation the supercharger has hitherto been considered as an "accessory" of the gasoline engine, designed to maintain the pressure at high altitudes. As long as this view prevails, however, it will not constitute so important an element of progress as it is capable of doing. The supercharger should be considered, at least for single-engine airplanes and for current altitudes of 5000 to 6000 m (16404-19685 ft.) as an essential part of the engine and not as a removable accessory.

It seems hardly necessary to use a supercharger near sea level simply to mix the gases. The importance of the supercharger will increase, however, with the use of heavy fuels. Before long we shall probably be using two-stroke-cycle and four-stroke-cycle scavenging engines on airplanes. In accord with the present tendency, we shall here present the French solutions of the problem in a practical rather than in a purely theoretical manner.

I. Turbo-Superchargers

Several years ago the Rateau Company made three turbo-superchargers for engines of 175 hp, 300 hp, and 450 hp, respectitely. The manufacture of the first one has been discontinued for the present. The second one has a maximum speed of 32,000 r.p.m., which restores the atmospheric pressure at 5500 m (18045 ft.), the ratio of the densities being 2:1. In this case the tangential velocity of the rotor is about 400 m/s (1312 ft./sec.). The 450 hp supercharger, being larger, rotates less rapidly (about 24,000 r.p.m.).

The shaft is flexible and rests on two ball bearings. The turbine has 92 vanes (fig. 1) and the fan has 10 radial vanes. At present the turbine vanes are set in

*From L'Aéronautique, March, 1931, pp. 101-109, and April, 1931, pp. 141-149.

the disk by means of tenons. In future they will be dovetailed. The end of the shaft nearest the fan is supported by a two-piece thrust bearing, which absorbs the lateral reactions. The other end is supported by a plain bearing and carries a worm gear for the tachometer drive (reduction ratio 20:1).

The turbine and fan are both made of chrome-nickel steel, treated to obtain great resilience. The shaft has a nickel content of 8%. The turbine vanes are made of tool steel. The bushings are lead bronze or regulus 88:12. The directive vanes are chrome-tungsten steel.

There are either two or three inlets for the exhaust gases, according to whether the engine is a V or W. The exhaust gases enter the turbine through tuyeres, which play an extremely important role (problem of injection). The gases then expand against the vanes and are evacuated through one or two orifices according to the engine type. The rotor, which must be perfectly balanced, is designed to function above the first critical speed, in the neighborhood of 8000 r.p.m.

The operating conditions of turbo-superchargers are severe, some of their parts having to work at a temperature of about 750°C, while other parts are subjected to the temperature of the surrounding air. Under such conditions the treatment of steels is difficult and the problem of the turbo-supercharger becomes a metallurgical problem. At present the life of such a mechanism is shorter than that of the engine.

The fan is light and compact. It can be rotated very rapidly. In 1917, Mr. Rateau, while investigating the rupture limit of rapidly rotating parts, attained a speed of 52,000 r.p.m. with a turbo-supercharger for the 175 hp engine. Its rotation proper absorbs very little energy, since the maintenance of the rotary motion does not, like reciprocating motions, periodically destroy the momentum of the moving masses.

It is well to note, however, that the fan is in constant communication with the compressed-air receiver and to refer, in this connection, to a recent report of the

National Advisory Committee for Aeronautics* (relative to a Roots type supercharger and not to a fan, though the conclusions are perhaps transferable). This report estimates at 26% the saving in power (fig. 2) at 20,000 feet from the use of valves which do not open until the intake air has been compressed to the desired pressure.

The head of the cylinder at the left in Figure 2 is provided with a calibrated valve. The piston first compresses the air to the desired pressure (curvilinear part of diagram: PL or PV = constant). The cylinder at the right has no calibrated valve. The piston head is continuously subjected to the pressure prevailing in the receiver. Hence it works against a constant pressure during its whole stroke. The supplementary expenditure of energy is represented by the hatched area. It is questioned whether such valves which, in the terms of the same report, add the complication of moving parts to simple mechanisms, can be advantageously mounted in the vicinity of the fan.

The turbine produces a braking effect on the exhaust. When the evacuation of the exhaust gases into rarefied atmosphere increases the engine output to the point that the gain in power (fig. 3) considerably exceeds (according to certain writers) the loss due to the operation of the supercharger, the interposition of a turbine creates a counterpressure on the pistons. Without denying this counterpressure, the Rateau Company claims that it is manifested mainly near sea level, where the turbine exhaust, creating a pressure near the atmospheric pressure, prevents the expansion of the gases from having its maximum effect.

Gains greater than those indicated by the theoretical curve in Figure 3 have been obtained in practice. Tests were made in 1928 at Chalais-Meudon on a Farman automobile engine which yielded 80 hp at 2400 r.p.m. The exhaust of this engine was connected with a box in which a centrifugal aspirator produced a negative pressure of about 300 mm (11.81 in.) of mercury. The engine, which then functioned under conditions of exhaust corre-

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*Technical Report No. 303 (1928): "An Investigation of the Use of Discharge Valves and an Intake Control for Improving the Performance of N.A.C.A. Roots Type Supercharger," by Oscar W. Schey and Ernest E. Wilson.

sponding to an altitude of about 5500 m (about 18000 ft.), developed 100 hp, a gain of 25% instead of 9% as indicated by the curve in Figure 3. Under these conditions it was found by extrapolation that a 500 hp engine, at whose intake a pressure of 1 kg/cm² (14.22 lb./sq.in.) is maintained, would develop 625 hp at 5500 m. If the 80 hp required for running the supercharger were deducted, the available power would be 545 hp, or a net gain of 45 hp.

Two reasons are given by Mr. Waseige in explanation of this gain: 1) The gases expand quicker and are cooled more; their temperature drop may amount to 250°C (450°F.). The danger of self-ignition is therefore reduced and the charge can be increased. 2) The exhaust gases remaining in the cylinder have a lower pressure than the fresh gas; when returned to the same pressure as the latter, they therefore occupy less space and leave more space for the fresh gas.

Mr. Rateau observes that there are two phases of the exhaust stroke to be considered.* First, the very short phase which follows immediately after the opening of the valve, while the piston, being near its bottom dead center, has a very low speed. As soon as the valve opens, the gases, being under a pressure of 2 to 3 kg/cm², (28.45 to 42.67 lb./sq.in.), escape at a velocity of several hundred meters per second. This pressure drops almost instantaneously. It is the "puff." The resistance offered by the turbine during these short intervals presents no disadvantage. The gases are supported by the piston head, at this moment almost stationary, and perform additional work.** Then, in the second phase, the

*This interesting idea was explained by Mr. Anxionnaz, the distinguished collaborator of Mr. Rateau, in a lecture before the "Société Francaise de Navigation Aérienne."

**This is, from another viewpoint, an analogous conception presented by Mr. Rowledge on the utilization of the gas expansion in the two-stroke cycle. During the first stroke, the gases work in a high-pressure cylinder and, during the second stroke, in a low-pressure cylinder. Here, the utilization at low pressure is represented by the turbine, and the high pressure is only a mean pressure, since gasoline does not allow compressions above 6, nor maximum pressures above 30.

piston drives the gases into the turbine, operating a sort of pneumatic power transmission with all the corresponding losses. The turbine evidently recovers only a part of the piston energy.

It is therefore obvious that the addition of a turbo-supercharger to a given engine, as an accessory, falls far short of realizing the highest possible efficiency. The cylinders of a modern engine, designed for the use of a supercharger driven by a gas turbine, should therefore, according to Mr. Rateau, have three orifices, namely, intake, exhaust-puff into the turbine and exhaust into the open air. The turbine would then function in periodic pulsations and would produce a variable pressure. Due to the extremely short duration of the puff, a valveless system would seem desirable. Such engines do not yet exist, the superchargers now used being mechanically controlled.

II. Rateau Supercharger with Farman Mechanical Control (Figures 4-6, 11-13)

This supercharger, whose first model weighed 50 kg (110.2 lb.), restores the atmospheric pressure at 6000 m (about 20,000 ft.). Since the mechanical control has to transmit 80 hp from the engine, which has a speed of 2150 r.p.m., to the supercharger, which turns at about 20,000 r.p.m., no clutch of the ordinary automobile type can be used. It is necessary, however, to throw into and out of gear without reducing the engine speed.

A "free-wheel" system enables the fan to run at the speed of the engine, even when the control gear is released. The drawings (figs. 5, 5a to 5j), which show the parts in their order of assembly, were made before the "free wheel" had been added. The latter is indicated, however, in Figure 5 and shown in Figure 6.

The step-up gear (figs. 5b and 5c), consists essentially of a plate with three pins on which are mounted three satellite gears. These mesh, on the one hand, with a fixed ring gear (fig. 5a) and, on the other hand, with a central pinion (fig. 5b) keyed directly to the fan shaft. There is thus obtained, in a small space, a speed increase of 9:1 for the Farman 12 W.E. engine. The pins carrying the satellites are set 120° apart and are held by a perforated triangular piece (fig. 5b). Their combined action, while functioning, produce a single moment distributed over a large number of teeth, a condition favorable to the wear of the latter. The lubrication of the satellite bearings is effected by deflectors which form grooves for the oil projected outside the bushings. The teeth are lubricated by projection and by a special device for the delivery of oil direct from the engine. The satellites are also provided with grooves for receiving the projected oil and with perforations in their rings through which the oil passes to the teeth.

The automatic clutch consists essentially of a movable disk (fig. 5d) on a special bearing independent of the engine. This disk, continually driven by the engine, by means of a shaft with a universal joint, turns between two friction plates carried by the parts b, c, and e. These plates are pressed together when the clutch control is operated. The movable ring gear (fig. 5c) is centered in the part b (fig. 5), the teeth forming guide grooves for the longitudinal movements.

The clutch is operated by means of a vertical lever visible in the gear case j. To this lever there are keyed two arms (fig. 5i) which engage in the cavities of the thrust block h. The operation of throwing into gear advances block h toward the engine and releases the tips of the weights (fig. 5g), which are normally held at rest by block h.

The weights are mounted on part f in such manner that their centrifugal force, when the plate revolves, tends to make them tilt or rock about their pivots. Under these conditions the case-hardened lug near the pivot of each weight is brought into contact with the rim of the movable ring gear (fig. 5e) which controls the clutch, by gradual action on disk d, which is driven by the engine.

In order to start plate f, each weight is actuated by a flat spring, as soon as the block h releases the tip of the weight. A certain pressure is therefore transmitted by these springs to the movable ring gear e, which effects the initial tightening of disk d and consequently the starting of the whole mechanism, consisting of the plate supporting the weights, the revolving ring, the satellite-supporting plate and the fan.

As the speed of the weight-supporting plate increases, the centrifugal force also increases and tightens the gear disk. The relative slipping of this disk with respect to its mount gradually diminishes, and the automatic engagement terminates when the weight-supporting plate and the ring gear acquire the same speed as the disk. This operation requires only 8 to 10 seconds. In the process of throwing out of gear, the arms i eliminate the centrifugal effect of the weights on the supporting plate of the clutch, and the weight-supporting plate gradually loses speed until it stops altogether.

The centrifugal clutch embodies sound principles under an apparent mechanical complication. It is flexible and very gradual, because the pressure on the movable ring gear is slight at first and does not reach its maximum value so suddenly as the ordinary spring mechanism. The driving moment varies proportionally to the square of the momentary speed of the weight-supporting plate. Since the resisting moment of the supercharger follows practically the same law, the capacity of the clutch to absorb the vibrations and the variations in the moment transmitted by the crankshaft and by disk d remains practically constant at all speeds. This is an essential characteristic.

In particular, for low engine speeds at which the moment transmitted by the crankshaft is generally very irregular, the clutch is still capable of slipping. The torsional vibrations or oscillations are not therefore transmitted to the step-up gears, as would be the case if the pressure on the clutch plate were constant and maintained its maximum value at all speeds.

The stresses on the weights offset one another and do not develop any radial component on the bearings. Neither are there any axial reactions during the automatic operation of the clutch. The weights act separately, without stressing the clutch or its operating lever while in gear. The force required to overcome the centrifugal force while throwing out of gear ceases as soon as this has been accomplished.

The body of the supercharger consists of two parts made of "alpax" (an aluminum alloy). Air is admitted to the center of the supercharger through an orifice in the first part, called the intake spiral. After being compressed by the first radial wheel, it is forced into a second spiral, where it is again compressed by another wheel before reaching the intake pipes. Packings are placed at both ends of the spirals to insure their tightness. The rotating shaft rests at both ends on bushed bearings. The vanes, of very resilient chrome-nickel steel, are dovetailed into the wheel. Being strictly radial, they yield no component parallel to the axis of rotation.

In the first superchargers made, the fan was stationary when the mechanical control was released. Concurrently with the installation of excessively long tuyeres on certain engines, there was introduced into the intake a braking effect, which caused a loss of 5 to 8% in power. Since it was important to avoid this loss and to produce a thorough mixing, even at a low altitude, the Farman Company introduced a "free-wheel" coupling device, which is shown in detail in Figure 6. The improved carburetion from the mixing offsets the power required to operate the fan.

The pawls of the "free wheel" (fig. 6) are provided with small weights. When the clutch is thrown out of gear, the pawls are engaged and consequently drive the supercharger shaft. The tips of the weights 6 (fig. 5) being arrested by block h, the coupling cannot take place and the rotational speed is the same as that of the engine. When thrown into gear, the movable parts gradually pass from the low to the high speed. Each pawl is then disengaged from its notch and freed from all friction, when the centrifugal force has acquired a certain value. The wear is thus greatly reduced.

When thrown out of gear, the speed of the fan diminishes gradually. The pawls engage in their notches under the action of their recall springs, then "free-wheel" till the speed of the fan shaft falls slightly below that of the engine. The pawls then engage and the rotor is driven at the speed of the engine.

The Rateau-Farman supercharger (fig. 4) is now a well-developed unit. Its characteristics are defined by Figures 7, 8 and 9. Tables I and II and Figure 10 give the results of the tests made on the Breguet 19 B.2 airplane by Cousin and Burtin. After the first tests, improvements were made in the mechanical control. The driving disk now rotates more rapidly than the crankshaft (7000 r.p.m.), which has enabled a reduction in the weight and size of the centrifugal clutch. On the other hand, the supercharger now has only a single stage. We will give a few details later regarding this point.

Figure 7 shows the air output of a Rateau-Farman supercharger in grams per second in terms of the altitudes plotted as ordinates for fan speeds of 10,000 to 20,000 r.p.m. The dash-dot lines are curves of equal efficiency.

Figure 8 shows the characteristic curves $\delta\mu$ and $\delta\rho$ of the Rateau-Farman supercharger. δ_m, output; μ, theoretical pressure; ρ, efficiency.

Figure 9 shows the maintenance of the power with increase of altitude by means of the three-speed mechanical control. Note that the power at 5800 m (19030 ft.) is slightly greater than at 3000 m (9840 ft.) - (a gain due to the exhaust into the rarefied atmosphere).

Figure 10 compares the speeds of a Breguet 19 airplane equipped with a 500 hp Farman engine, both with and without supercharger.

III. Three-Speed Mechanical Control

When the supercharger is in operation, it is not possible to open the valve wide at low altitudes, and there is always considerable waste of energy. In order to remedy this disadvantage, the Farman Company introduced a three-speed mechanical control.

TABLE I

Test No. 9 (March 22, 1929). Pilot, J. Burtin. Observer, Cousin.
Breguet 19B2 airplane. Farman 12WE engine. Rateau supercharger with mechanical control.
Levasseur two-bladed propeller of 4 m (13.12 ft.) diameter. Total load, 2500 kg (5511.6 lb.)
Climbing time, 4 min. 3 sec. per 1000 m (3281 ft.)

Altitude	Outside pressure	r.p.m. of engine	r.p.m. of supercharger	Pressure produced (read)	Pressure produced (corrected)	Outside temperature	Temperature of compressed air	Temperature of intake mixture	Temperature of water		Temperature of oil	Air speed	Remarks
m	mm			mm	mm				in	out		km/h	
0	753	1440				+15°							
1000	657	1500				+10							
2500	532	1660	15200	250	802	- 3	+52°	+22°	55°	87°	65°	120-130	Supercharger thrown into gear during climb
3000	520	1700	15600	280	800	- 8		+27	-	-	-	-	
4000	454	1790	16400	330	784	-11		+30	-	-	-	-	
5000	420	1800	16600	310	730	-15	+55	+29	50	75	60	-	
6000	353	1900	17500	347	700	-26		+27	-	-	-	-	Supercharger wide open
7000	335	2000	18400	335	670	-32	+42	+25	30	60	52	-	
8000	270	2100	19300	360	630	-38	+40	+19	-	-	-	-	
													Level flight
6200	-	2080	18950	380	730	-	+55	+28				180-190	I. Full throttle
5200	-	2100	19300	365	765	-	+58	+32				190-200	II. " "

TABLE II

Test No. 19 (July 23, 1930). Pilot, J. Burtin. Observer, Cousin.
Breguet 19B2 airplane. Farman 12WE engine. Rateau supercharger with mechanical control.
Chauviere four-bladed propeller of 3.5 m (11.48 ft.) diameter. Total load, 2250 kg (4960.4 lb.).
Gasoline with 30% benzol. Climbing time, 4 min. per 1000 m (3281 ft.)

Altitude m	Outside pressure mm	r.p.m. of engine	r.p.m. of supercharger	Pressure produced mm	Intake pressure of engine mm	Outside temperature	Temperature of compressed air	Temperature of intake mixture	Temperature of oil	Fuel pressure g	Air speed km/h	Remarks
0	758	1320				+17°				280		
1000		1590			570	+ 5					120-130	During climb.
2000		1600				0		+ 2°				
2100		1650	15200	700	680	0	+65°	+25	+70°	-	-	Throwing supercharger into gear.
3000		1760	16200	735	720	- 3	+68	+35	-	190	-	Supercharger wide open.
4000		1900	17400	-	720	- 9	+72	+36	+65	-	-	
5000	420	1950	18000	750	730	-16	+75	+35	-	100	-	
5000		2200	20300	780	760	-16	+77	+37	+72	100	195-200	Level flight I. Full throttle.
-		2150	19600	770	755	-16	+75	+35	-	-	195	II. Intake reduced 1/5.

The first speed is used only for the ground mixture and absorbs 5 to 8 hp. The second and third speeds absorb, respectively, 22 and 80 hp in restoring the pressure at 3000 m (about 10,000 ft.) and at 5600 m (18,373 ft.). For each of the first two speeds there is a free wheel provided with pawls operating under the action of the centrifugal force. This free wheel enables the gearing in which it is mounted to revolve more rapidly than the mechanism which drives it. There is therefore no need of any throttling or gear release in passing from one speed to another. A single lever in three positions renders it possible to release the gears successively. Figures 11, 12, and 13 and their legends explain the operation of this remarkable mechanism. The Farman Company considers that the three speeds afford a sufficient range for normal present-day airplanes.

Diagrams of the Farman Three-Speed Mechanical Control

First speed, so-called mixing speed (upper half of Figure 12).- Wheel d, keyed to the engine shaft, actuates wheel e by the intermediation of the sliding joint f, and pinion b drives wheel a with the aid of ratchet c and pawls p. (Fig. 11.) The pawls can be replaced by rollers acting on the principle of a wedge. The supercharger wheel is then geared to 11,000 r.p.m. for a nominal engine speed of 2500 r.p.m. and produces an excess pressure of about 5% in the intake pipes. At this instant the gears are released, i.e., the ball bearing k is in contact with the tips of the weights g (fig. 12) and prevents the latter from pressing on the friction disk near plate h.

Second speed (lower half of Figure 12).- When the weights g are freed by moving lever j, the ring gear l is engaged by the pressure with plate h, and the supercharger wheel turns at 17,000 r.p.m. restoring the pressure of 760 mm (29.92 in.) Hg up to 3000 m (9842 ft.). While running at speed 2, the supercharger wheel revolves faster than at speed 1, and the gear wheels likewise turn faster. The pawls p of speed 1 are then actuated by the centrifugal force and freed from the ratchet c, thus breaking the connection between pinion b and wheel a. The gearing of speed 1 is then said to be in the "free-wheel" position.

Third speed (fig. 13).- Continuing the operation of lever j, the weights of each of the two clutches are liberated. The ring gears m are driven, with the aid of gears d and n, at a multiple of the crankshaft speed. The supercharger wheel then turns at 27,000 r.p.m. and a pressure of 760 mm (29.92 in.) Hg is maintained up to about 5800 m (19029 ft.). While running at speed 3, the free wheel of speed 2 acts the same as that of speed 1 and the connection is likewise broken between the control shaft and the second speed gear. Contrary maneuvers enable running at speed 2 and then at speed 1. Note, on Figure 11, that the gears of speed 3 are two in number. This method was adopted partly to enable the transmission of the maximum power of the supercharger within a small space and partly to balance the stresses on the bearings of the supercharger wheel.

The process of throwing in and out of gear consists simply in moving lever j from one position to another, without any special precaution. The control lever of the supercharger can be set as desired. The maximum force for releasing the control lever is about 15 kg (33.1 lb.). This force ceases as soon as the release has been effected.

IV. Other Mechanical Controls

Before describing the new volumetric superchargers, it is interesting to examine other mechanical controls, which cannot be thrown out of gear, for centrifugal superchargers. As typical examples, we will consider, on the one hand, the control originated by the Bristol Company for the well-known Jupiter engine, which combines very satisfactory solutions of the problems posed (great multiplication, gradualness of engagement, elasticity of control) and, on the other hand, the more recent and simple Renault control on their 700-850 hp engine.

Mechanical control of the Bristol supercharger.- The fan revolves normally at 17,750 r.p.m., the multiplication of 10:1 being obtained in two stages. The elastic control (figs. 14, 15, 16) comprises a steel hub h held on a conical bearing of the crankshaft. This hub actuates wheel f (or A, fig. 16) by means of compression springs g seen endwise in Figure 14. The springs are located between six pairs of centering notches (six notches on the hub and six others on the wheel). This device deadens the torsional vibrations at the end of the crankshaft and prevents their transmission to the step-up gears. Bronze rings i center the wheel f on its hub h.

Wheel f engages three pinions d, which revolve on roller bearings carried by fixed axles o (which are held by grooves in their heads and penetrate the aluminum casing n and a). Ring e connects the heads of these axles. The teeth of pinions d are lowered at c and form grooves to which are keyed the hubs b of the three return wheels, one of which is shown at k. These three wheels drive the pinion at the end of the fan shaft u and contain the centrifugal clutches which limit the moment.

The hubs b of the recall wheels have a central partition cut in such a way as to form sockets for the bronze engaging blocks a. These blocks, which are shaped like the segments of a ring, can move only in the radial direction. Projected outward by the centrifugal force at the moment of starting, they exert a strong pressure inside the wheels k. The resulting friction suffices to insure first the starting and then the transmission of the moment to the vane wheel.

When the engine is subjected to sudden accelerations which may produce very violent stresses on the transmission gear, the engaging blocks slide. On the other hand, they uniformly distribute the stresses between the three return wheels, since the clutch, thus accidentally loaded, slides until uniform distribution is reestablished.

The vane wheel p, of forged steel (fig. 27), has 16 radial vanes which taper at their tips. It is mounted by means of grooves r on shaft u which rotates concentrically with the crankshaft without being supported by it. The legend of Figure 14 (Bristol supercharger) defines certain other details, as follows: a, bronze engaging block; b, hub of return wheel enmeshed at c by grooves on return pinion d; e, crown of return axles; f, drive wheel; g, spring of elastic control; h, hub of drive wheel; i, bronze hub rings (centering wheel f); j, intake chamber from which the intake pipes go to the cylinders; k, return wheel which contains the engaging blocks a; l, crankcase rib; m, vane disk (It is between these disks, whose divergence determines the gradual increase in the sections of passage, that the kinetic energy of the air is converted into pressure); n and q, casing; o, axle of return wheel; p, vane wheel mounted by grooves at r on shaft u; s, ring for holding oil; v, oil collector; w, supercharger case; x, intake spiral.

Mechanical control on the 700-800 hp Renault engine.- The rotor being required to produce an excess pressure of only 150g/cm² (2.13 lb./sq.in.), its rotational speed was limited to about 15,500 r.p.m. Under these conditions, Renault thought best to use neither a centrifugal clutch nor a sliding joint, in order to make his mechanical control as simple as possible. Its construction is illustrated by Figure 17 with its legend, as follows:

a) Front view of step-up or multiplying gears, visible through the cutaway near the bottom of the case. Here the calibrated pinion is keyed to the end of the crankshaft. The multiplication of about 7:1 is effected in two stages by simple straight gearing. It is known that Renault uses a similar system in his reduction gears, of course, with parts proportioned to the moment to be transmitted.
b) Supercharger cover containing two horizontal orifices (only one of which is visible), to which the carburetors are attached. These orifices expand inside the cover into two chambers, whose slightly helicoidal partition is visible through the central opening.
c) Rear view of the fan or blower in its casing. The rotor is duralumin. Its vanes are supported by webs included in the casting. The hollow outside vanes are supported by a disk which is secured by nine bolts, one for each vane. There are shown at the top the three orifices, each of which supplies a group of four cylinders. The perspective renders it hardly possible to discern the boss in which turns the pinion keyed to the end of the crankshaft, which is situated on the opposite face. The casing is closed at the rear by the cover b.

V. Volumetric Superchargers

These superchargers are now the subject of intensive research. Two very ingenious examples have been presented: one with pistons (Dugelay-Worthington), the other with rotating blades (P.Z.). We shall now consider only the structure of the superchargers and not that of their controls. They are, in fact, designed for direct drive.

The Dugelay-Worthington supercharger (fig. 18), now being tested by the Services Techniques, has two horizontal reciprocating cylinders. The first type made was designed to be attached directly to the shaft of an engine having a cylinder displacement of 22 liters (1342 cu.in.) and to develop a power of 350 to 400 hp at 7000 m (about 23000 ft.). The most modern devices were employed in its construction (needle bearings, flexible blades instead of valves, etc.). It has, moreover, been lightened to the maximum by the use of magnesium, elektron and duralumin, so that its total weight is only 26 kg (57.3 lb.).

The crankshaft carries a plate k with needle bearings. The bearing shafts are of CN5 steel, treated and drilled. The connecting rods l, in the form of equal-resistance solids, are of nitrided steel.

The pistons g, of light metal cast under pressure, are hollow with interior reinforcing ribs. Their height has been reduced to the minimum in order to eliminate dead spaces in so far as practicable. Since jamming might occur under these conditions, two guide rods e, are provided on which the piston slides with bushings of self-lubricating metal and does not rub against the cylinder wall. Tightness is insured by a graphite ring held in contact with the cylinder wall by springs. This original device enabled the use of light metal for the cylinders. Graphite was already used for the brushes of electric generators. It there rubs on various metals at tangential speeds of the order of 20 m (66 ft.) per second and withstands pressures comparable to those produced in superchargers. The piston pins have needle bearings.

The cylinders, cast under pressure, are provided with ribs which increase their strength and accelerate the evacuation of heat. They are assembled by rods. The intake is through the cylinder heads (at a in the upper chamber). The exhaust occurs laterally. One of the annular chambers is represented at d and one of the flexible clapper valves at f.

The customary intake and exhaust valves are replaced by elastic disks of very small inertia. Only the intake disks c, are controlled by a system of cams and push rods of polished nitrided steel and duralumin rockers (i, h, b). The sensitive automatic exhaust valves are mounted in easily accessible removable housings.

The balancing was given special attention. Since the cylinders had a common axis, the piston reactions balanced one another. The big ends of the connecting rods are balanced by counterweights. The connecting-rod bodies alone develop a moment which can be largely eliminated by an adjustment of the masses.

The lubrication of the cam controls is tight and has, at the bottom, a tank of oil in contact with the cams. A volumetric pump, controlled by a worm gear and delivering one drop a minute, supplies the connecting rods.

<u>Characteristics</u>.- Bore, 250 mm (9.84 in.); stroke, 160 mm (6.3 in.); volume of one cylinder, 7.85 liters (479 cu.in.); total cylinder displacement per revolution, 31.4 liters (1916 cu.in.); per minute at 1700 r.p.m., 53.38 m^3 (1885 cu.ft.). The volumetric efficiency being 85%, the volume drawn in at the pressure of the surrounding atmosphere is 45.37 m^3 (1602 cu.ft.).

If we now consider an engine of 22 liters (1342 cu.in.) cylinder displacement, running uniformly at 1700 r.p.m. at 85% volumetric efficiency, the volume actually drawn in is 15.89 m^3 (561.15 cu.ft.). The ratio of the displaced volumes is then

$$\frac{45.37}{15.89} = 2.85.$$

The exhaust ability of this supercharger exceeds 700 mm (27.56 in.) Hg. The power absorbed without load is about 6 hp. The power absorbed with load at 7000 m (about 23,000 ft.), enabling the restoration of a pressure 1.037 kg/cm^2 (14.75 lb./sq.in.) to the engine in atmosphere rarefied to 38%, is about 35 hp. The over-all efficiency is 55 to 60%.

<u>The "P.Z." supercharger</u>.- The numbers and letters refer, respectively, to Figures 22 and 23-24. Three photographs are shown in Figures 19, 20, 21.

The P.Z. supercharger consists of a cylinder, in which rotate two 3-blade systems such as m set at 120° and integral with two coaxial shafts k and l. These shafts carry, respectively, the crankpins M_1 and M_2 to which are attached by yokes the connecting rods B_1 and B_2 or j. The large ends of these rods are jointed at e to two pinions, such as c, which turn inside a fixed double-toothed ring a. The pinions, having a diameter one-third that of said ring, are borne by a driver f revolving on rollers at g and on balls at g'. If force is applied to the motion piece by means of the grooves h, the two three-bladed systems, in revolving, approach and recede from each other three times per revolution, due to the hypocycloidal motion of the large ends of the connecting rods B_1 and B_2. In short, the blade assembly is endowed with alternating rotary motions with respect to the fictive blades which revolve uniformly inside the cylinder. (The over-all length is 315 mm.)

The positions of nearest approach of the blades are situated at three points α, β, γ (fig. 23), spaced at 120° on the fixed cylinder. On each side of these three points there are placed three sets of ports A_1 R_1, A_2 R_2, A_3 R_3 (A_2 and A_3 not shown). There is always a blade between these ports. If the intake ports A_1, A_2, and A_3, on the one hand, and the exhaust ports R_1, R_2, and R_3, on the other hand, are joined by manifolds, we have a lift pump and a force pump.

The six blades define six chambers of variable volume. Since each blade occupies a dihedral angle of 20°, the maximum volume of a chamber corresponds to a dihedral of 80°. Thrice during each revolution this dihedral closes and then resumes its maximum volume, delivering a volume of air corresponding to a rotation of $80° \times 3 = 240°$, that is, to two-thirds of the cylinder. The six chambers therefore supply a volume equal to four times that of the cylinder tangent to the blades. An apparently difficult problem has thus been successfully solved, namely, to make a supercharger deliver, per revolution, several times its own volume.

The legends accompanying Figures 22 to 24 indicate all the details, as follows:

Figure 22.- Longitudinal section.- a, fixed double ring gear; b, cover; c, double pinion borne by

the driver (at the bottom, the counterpoises of the large ends of the connecting rods); d, bearing of double pinion, mounted on needles and having, in the center, a case-hardened stud; e, large end of connecting rod mounted on needles; f, driver revolving on rollers at g and on balls at g'; h, grooves for transmitting motion to driver; i, ring gear holding set of blades along axis of rotation (This gear holds a shoulder of shaft l); j, large end of connecting rod mounted by a yoke and needles on a crankpin integral with shaft k; k, hollow shaft rotating inside shaft l which it supports (k rotates on two needle bearings at its ends, one being centered in carrier f, the other clear to the rear, and l rotates about k on two needle bearings); m, blade assembly and intersection of inside ribs; n, assembly of blade on a longitudinal stud of hub p; o, grooves traced on a shoulder of shaft k for driving the hub carrying stud p; a, pressure-regulating valve, held by spring s and controlled by lever r operated by the pilot.

Figure 23. Cross section showing the two 3-bladed systems.- α, β, and γ, lines along which the blades approach the nearest; A_1, A_2, and A_3, intake ports of 19° aperture; R_1, R_2, and R_3, exhaust ports of 15° aperture; ZZ', arc of 12° astride the line α, along which the blades form a practically constant dihedral of 2°. Note assembly of blades on tenons of one of the hubs.

Figure 24. Cross section showing driving mechanism of coaxial shafts.- The satellite pinions, whose axis is borne by the carrier, rotate inside the fixed ring. The large ends of the connecting rods B_1 and B_2 describe three-loop hypocycloids, which communicate to the crankpins M_1 and M_2 a motion resulting from the superposition of oscillations on a uniform rotary motion. The coaxial shafts k and l are here shown endwise, separated by the needle bearing.

We will here call special attention to certain structural details. It was sought to lighten as much as possible the revolving parts subjected to variable periodic accelerations.

The elektron blades, forged and reinforced on the inside, consist of two shells riveted to the longitudinal tenons of the hubs. The thickness of their walls and rims varies between 1.5 and 2 mm (0.06 and 0.08 in.). Each blade weighs only 130 g (0.287 lb.). Moreover, the larger part of the material is near the hub, so that, at 2000 r.p.m. the maximum force exerted on a connecting rod is only 800 kg (1763.7 lb.), disregarding reactions due to the compressed air. This force is small in comparison with the forces exerted on the connecting rod of an aircraft engine, but it is still further reduced in operation. It has been found, in fact, that the compression stresses are directly opposed to the inertia forces and, under a discharging force of 500 g/cm² (7.11 lb./sq.in.), for example, the relief to the connecting rods amounts to 40%.

Moreover, knowing that the inertia stresses are greatest when the blades are near together, we can, by suitably adjusting the big ends of the connecting rods on the pinions, obtain an accompanying movement of the blades which eliminates the effects of the point of pressure. It is at an angle of about 12°, affecting the arc ZZ' (fig. 23) as regards the direction α, that the blades come the nearest together and have practically equal speeds. The air cushion between them, a cushion which corresponds to a dihedral of about 2°, and which is obtained by an intentional staggering of the intake and exhaust ports, tends to retard the blade which is slowing down and to accelerate the one which is picking up. A supplementary relief of the connecting rods is thus obtained. The loss in output, due to the blades not coming exactly in contact, is only about 3%. At ordinary engine speeds the supercharger runs without vibration and gives the same impression as a mechanism with a uniform rotational motion.

In order to avoid all overhang, the ring gear, with which the pinions mesh, is double, the pinions themselves are double and the connecting rods are forked. The joints and the coaxial shafts are mounted on Nadella needle bearings requiring very little oil and well suited for the contemplated loads and speeds.

The width of the blades at their ends is favorable to tightness. Despite the anticipated expansion, the losses are considerably reduced, even if the air drawn into the supercharger is dry and, if it is carbureted, the tightness becomes perfect, the small droplets distributed over a large surface forming a hydraulic seal.

The adjustment is by means of the internal circulation. The rear end of the cylinder is closed by a plate q, with a conical base against which the blades revolve. This plate is normally held against its seat by a spring s. A lever makes it possible, by opposing the action of this spring, to raise the plate from its seat and establish direct communication between the chambers alternately subjected to compression and suction.

The valve is wide open at sea level, the supercharger only serving to mix the gases with the least expenditure of power. The gradual closing of the plate makes it possible to increase the pressure with all the precision desired. Lastly, the system acts as a safety valve against back-firing.

The prototype of the P.Z. supercharger was designed to be geared directly to the shaft of a 350 hp engine revolving at 2000 r.p.m. The cylinder has a bore of 190 mm (7.48 in.) and a length of 200 mm (7.87 in.). The blades cover 20°. The theoretical output is 21.4 liters (1306 cu.in.) per revolution. Length, 315 mm (12.4 in.); maximum diameter, 270 mm (10.63 in.); weight, 17 kg (37.48 lb.). The P.Z. supercharger is now undergoing tests for plotting the efficiency curves.

VI. Comparison of Different Supercharger Types

It is rather difficult to apply a coefficient of quality to the various formulas. The efficiency and the requisite power do not suffice. The weight and the installation details must also be considered.

Turbo-superchargers.- Many think the exhaust gases constitute an undesirable residue and that the utilization of their energy, interesting in theory, gives rise, in practice, to more trouble than profit. In any case, the turbo-supercharger has not yet said its last word, especially on large engines.

The centrifugal supercharger is compact. It is especially suitable for radial engines (figs. 25-28), in which it generally suffices to improve the step-up gear, as the fan is already present and performing the office of mixer.* It must revolve very rapidly, however, and the questions of ball bearings and lubrication become quite troublesome.

Evolution of Armstrong-Siddeley Superchargers

Figure 25, type I (1925).- From left to right: intake blades; supercharger in casing, rotor. Intake blades are fixed. Rotor is duralumin, mounted on engine shaft by fine grooves. Exit blades are straight. Note large number of blades and space between them and the rotor.

Figure 26, type III (1930).- Rotor has more blades than in type I. They are reinforced by a disk cast in one piece with them. The steel intake blades are incorporated in the rotor and form incurved elements for deflecting the air toward their roots. Dovetailed into the mass, they are held in place by pressure on the hub. The penetration of the bases of the steel blades into the front edges of the duralumin blades unites the two pieces intimately.

The pressure supplied by it varies much more with the speed than that produced by volumetric superchargers. Since aircraft engines revolve at more uniform speed than automobile engines, this objection would be more applicable to the latter. The fan works constantly under the conditions of counterpressure already indicated. The mechanical controls and clutches are still delicate instruments, despite all the care exercised in their construction. Their efficiency is of the order of 60-65%.

The volumetric supercharger appears to have a higher efficiency, but it is more cumbersome. The high compression ratios, made possible at very high altitudes, seem to offer decided advantages, e.g., flights at 15,000 m

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*Note, in this connection a remark by Mr. Waseige. The prospects for superchargers seem more promising on water-cooled engines, where the cooling capacity can be increased, than on air-cooled engines, where all the available surface of the cylinders is already covered with fins and does not seem able to insure, without complications in the ventilation at very high altitudes, the supplementary cooling necessitated by the conservation of the power. However, it is only fair to recall that the world altitude record was won by an air-cooled engine.

(49200 ft.), if such flights are possible, which has not been proved, there being very few data on the efficiency of propellers at speeds above the velocity of sound in the air.

It can be foreseen that, on large multi-engine airplanes, the supplying of the carburetors and air cabins at one atmosphere will be the object of tests of distribution by a central plant. For the solution of this problem, we have the explosion engine, whose cylinders and movable accessories are immediately transposable.

A 500 hp four-stroke-cycle engine consumes about 500 liters (17.66 cu.ft.) of fuel mixture per second. In functioning as a two-stroke-cycle pump, it would deliver, at 5500 m (18000 ft.), a practically equivalent volume of air at atmospheric pressure. The delivery might be doubled by using reciprocating cylinders.

The structural weight of such a supercharger, aside from the engine, might be considerably reduced by the elimination of all the accessories and a great reduction in the weight of all the parts calculated for the maximum pressure of 2 kg/cm² (28.45 lb./sq.in.), instead of 30 kg/cm² (426.7 lb./sq.in.). (It is only necessary to recall the remarkable results obtained in this way by the Dugelay-Worthington supercharger.) The speed increase would be made possible by lightening the movable accessories. We would then have, for a bulk comparable to that of a 500 hp engine, if it be assumed that the rotational speed can be doubled (which appears quite possible under the contemplated working pressure), a supercharging plant capable of supplying four 500 hp engines at 5500 m (18045 ft.). This plant would be operated by a special engine with change-speed gear. The weight cannot be accurately computed, but would probably be less than the weight of four ordinary superchargers.

VII. Problems Involving the Accessories

The maintenance of the pressure at high altitudes entails modifications in the installation of the accessories, which are rendered increasingly necessary as the compression ratio increases.

There being only one air intake, it is important to give it the best form to convert the velocity of the air into pressure, an expedient which is increasingly productive as the speed of the airplane increases.

If the carburetor is placed between the supercharger and the cylinders (fig. 31), communication must be established between the float chamber and the collector. This method of mounting does not profit from the effect of the mixing and requires special adjustment of the fuel pump which must supply the float chamber at excess pressure. If, on the other hand, carburetion takes place before compression, a single carburetor suffices, and ordinary fuel pumps can be used. A carburetor, however, which is supplied at a high altitude by air of small density, must have a large passage, which is too large at sea level. In this case an automatic altitude control would be of special interest.

Back-firing must be avoided in the large exhaust manifold of the supercharger, which always contains several liters of the fuel mixture. The Farman Company uses, in addition to the customary nonreturn valve on each cylinder intake pipe, a collector valve (fig. 29). Lastly, it is necessary to provide an inlet valve at the entrance to the supercharger and calibrated valves for the exhaust, in order to avoid any accidental overpressure in the pipes.

The rise in temperature due to compression is expressed by the formula

$$T = T_0 \left(\frac{p}{p_0}\right)^{\frac{n-1}{n}} \quad \text{with} \quad n = 1.4,$$

corresponding to an adiabatic compression. The air does not leave the present superchargers at a temperature above 75°C (167°F.). Radiators with large aluminum tubes give satisfaction.

It is necessary to overdimension the water and oil radiators, since the radiating areas ordinarily provided may be insufficient in rarefied air, notwithstanding the increase in speed.

In a supercharger with the Farman mechanical control, the oil provision is very large, 150-180 liters (39.6-47.6 gal.) per hour. It necessitates a special mounting, as shown in Figure 30, which has the following legend.

Figure 30.- Oil circulation of Farman 12 WE engine, equipped with a mechanically controlled Rateau supercharger. a, oil radiator; b, intake of drain pump connected with sump h; c, oil filter; d, excess-pressure valve; e, oil distributor; f, plug for emptying oil; g, oil pipe to clutch of step-up gear and to bushing in front of supercharger; i, return of oil from drain pump to tank n; j, oil pipe from tank to pump; k, pipe to manometer M; l, oil pipe to adjustable connection m and thrust bearing of supercharger; A, lever of mechanical control.

Figure 31.- Diagram of fuel system on Farman 12WE engine equipped with a Rateau mechanically controlled supercharger (air blown past carburetor). The air pipes are hatched, while the fuel pipes are indicated by heavy parallel lines. A, from fuel tank; C, carburetor Zenith 60 D.J.P., tight; D,D', air distributors; K, supercharger; M, compensated manometer; P,P', A.M. fuel pumps; $R_1 R_2$, air coolers; T, equilibrium tube; a_m, inlet for compressed air going to manometer; a_r, inlet for compressed air going to distributors D and D' through radiators R and R'; d, optional fuel-pressure regulator; p, pump for injecting fuel into the intake pipes; v, fuel cleaner.

The carburetor C is tight. The equilibrium tube T connects the free space above the float chamber with the compressed-air current in front of the Venturi tube. Without this precaution, the pressure in the Venturi tube would be greater than that above the float chamber, and the fuel would not be drawn in. The float chamber being thus under excess pressure, the A.M. fuel pumps (normally adjusted to work under a pressure of 250 g/cm² (3.56 lb./sq.in.) would not be able, above a certain limit, to raise the needle valve and insure the fuel flow. A pipe at a_r conducts compressed air to the distributors D and D'. This air is admitted to the inside of the elastic deformable piston of each pump and augments the action of the discharge spring. However, being hot, there is danger of causing, through the metal wall of the piston, a vaporization of the fuel which would disturb the circulation. It is cooled, therefore, in two small radiators R,R'. These do not, therefore, represent in any way the radiator through which passes the air going to the engine and which is not shown here.

Magnetos.- The resistance between the electrodes of the spark plug remaining constant, the current has just so much greater tendency to pass to the spark arrester as the density of the dielectric surrounding air diminishes. This difficulty is remedied by shielding the magneto (or at least the spark arrester, which then functions in an atmosphere under constant pressure), or by making the distance between the electrodes of the spark arrester adjustable. For further details, see analysis of the French patent 648,361 by Mr. Poincaré (No. 126, page 372).

Propellers.- In order to maintain the maximum efficiency, it is possible to act on three parameters - D, n, and h. One dreads to contemplate the construction of propellers with diameter variable in flight. As regards n, the problem merits the attention of technicians. T. B. Barbaroux has invented a two-speed reduction gear for aircraft engines, which shows that the problem is being studied. So far as we know, however, it has not yet been solved. The most accessible parameter at the present time is h. It is evident that propellers with pitch variable during flight are necessary for high-altitude engines.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

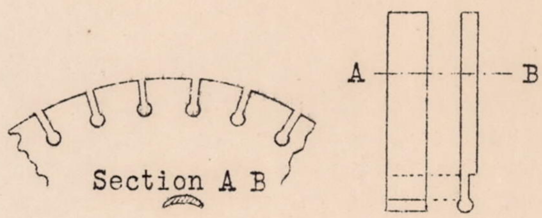


Fig.1, Tenon mounting of Rateau turbine vanes

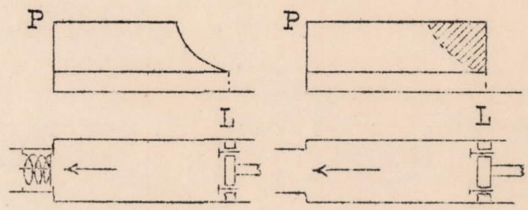


Fig.2, Comparative curves of the work of compression

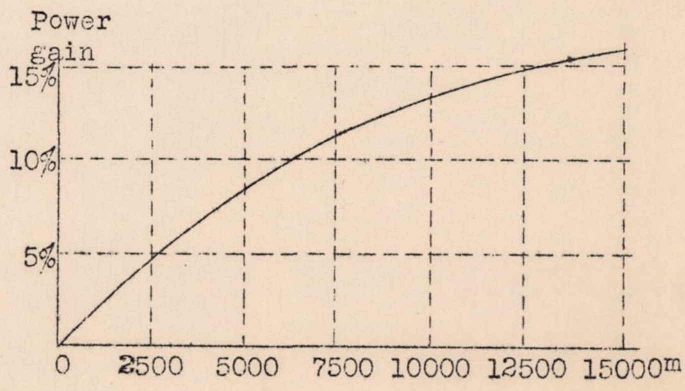


Fig.3, Calculated gain in power resulting from exhaust into rarefied atmosphere.

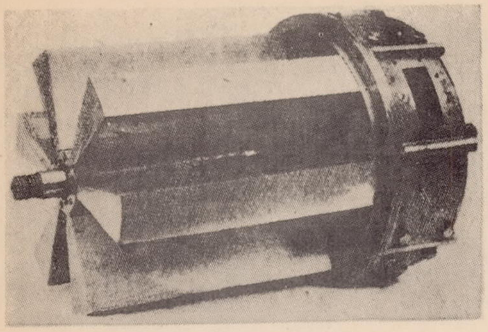


Fig.19 Revolving blades.

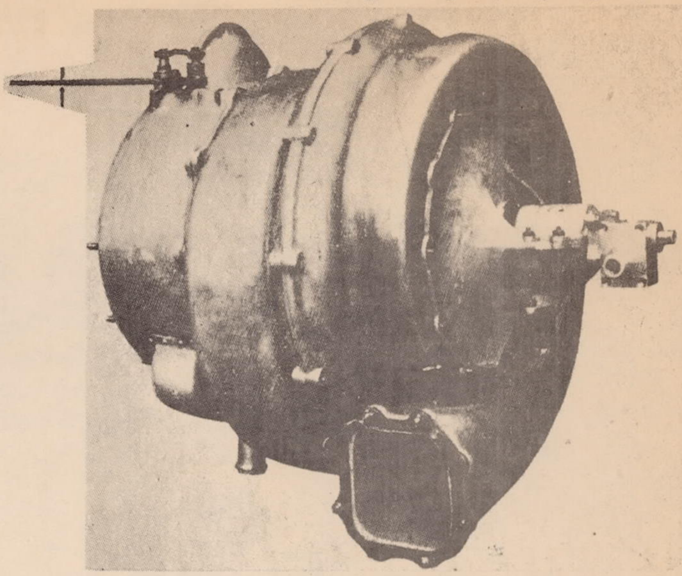


Fig.4 Rateau supercharger with Farman mechanical control. Clutch control lever at upper left.

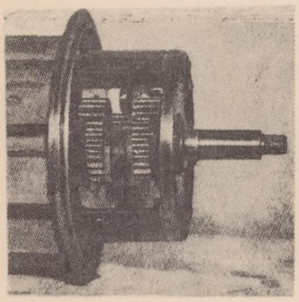


Fig.20 Driving gear.

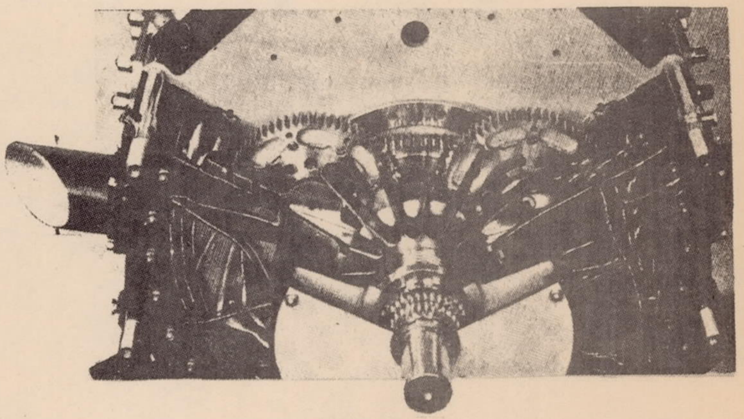


Fig.15 Sectional photograph of the Bristol supercharger.

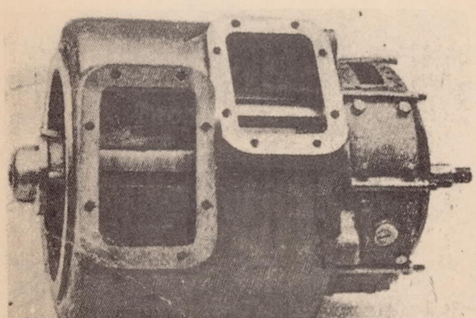


Fig.21 Outside view.

Figs.19,20,21, P.Z. supercharger

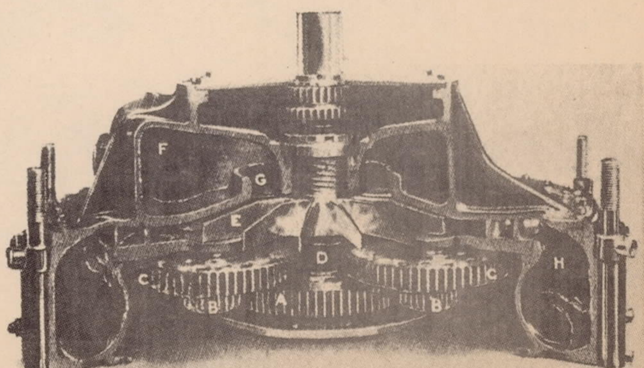


Fig.16 Sectional photograph of the Bristol supercharger.

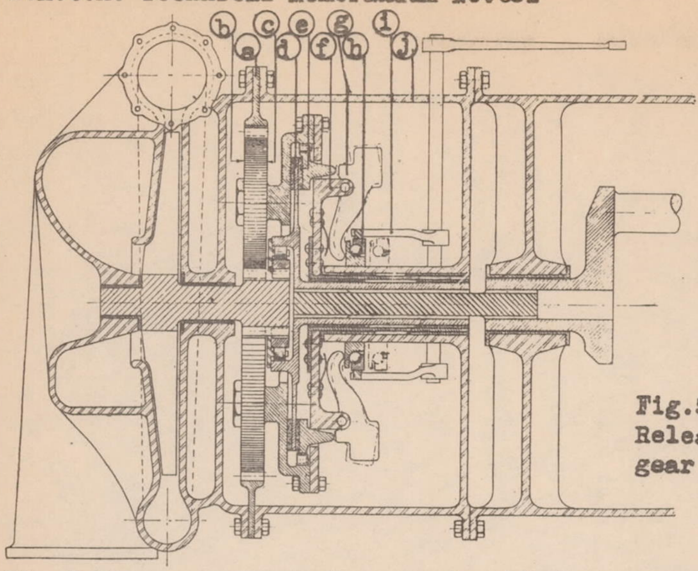


Fig.5,Farman mechanical control of Rateau supercharger. (In reality this supercharger has two stages)

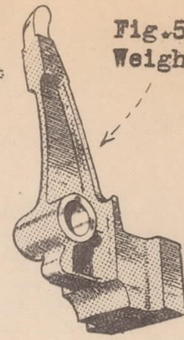


Fig.5g Weight

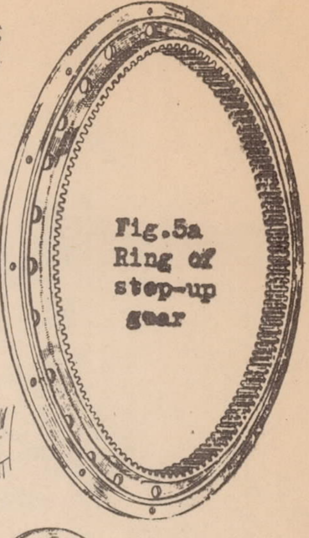


Fig.5a Ring of step-up gear

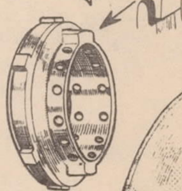


Fig.5h Releasing gear

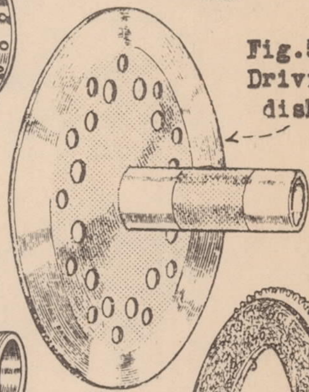


Fig.5d Driving disk

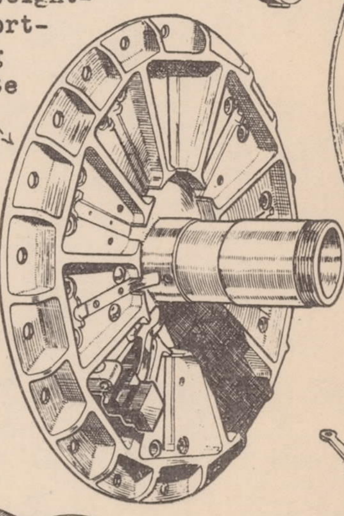


Fig.5f,Weight-supporting plate

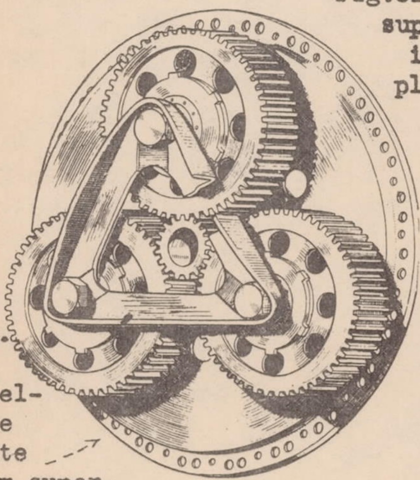


Fig. 5b Satellite plate from supercharger side

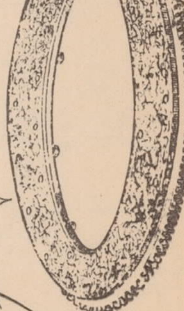


Fig.5e Clutch-supporting plate

Fig.5i Fork-forming levers

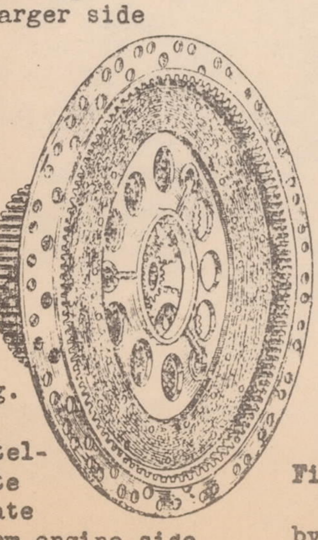


Fig. 5c Satellite plate from engine side

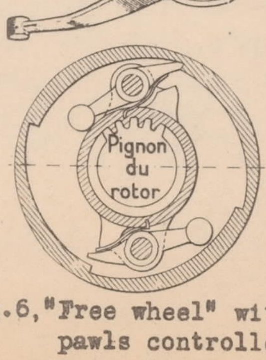


Fig.6,"Free wheel" with pawls controlled by centrifugal force

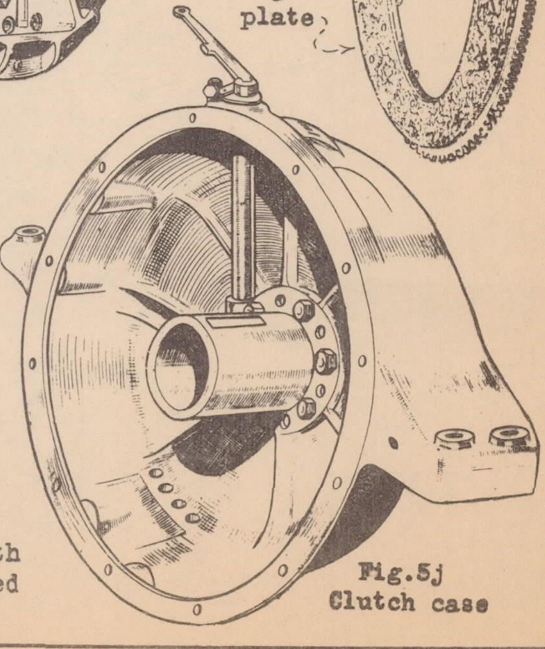


Fig.5j Clutch case

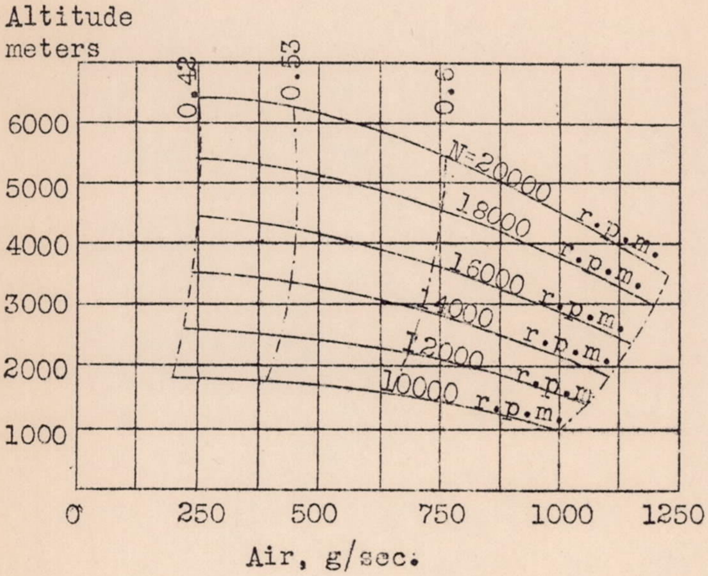


Fig. 7

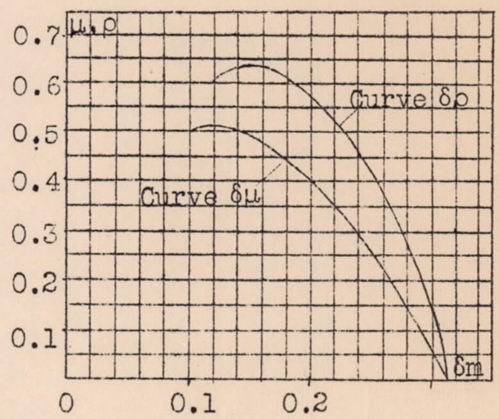


Fig. 8

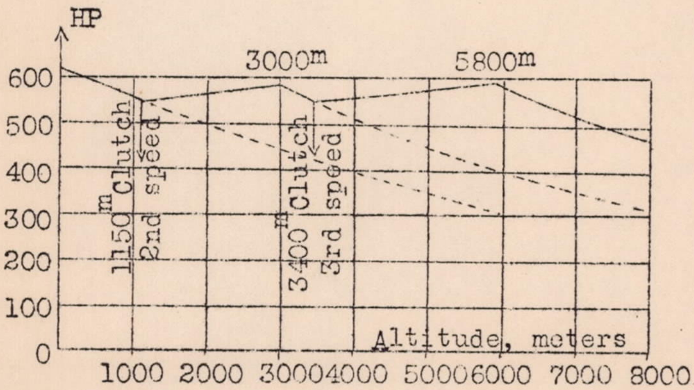
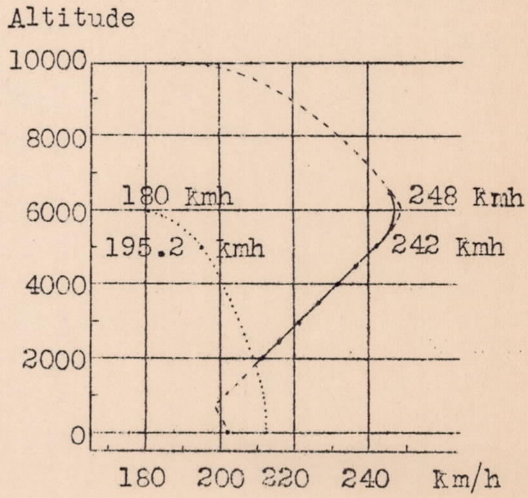


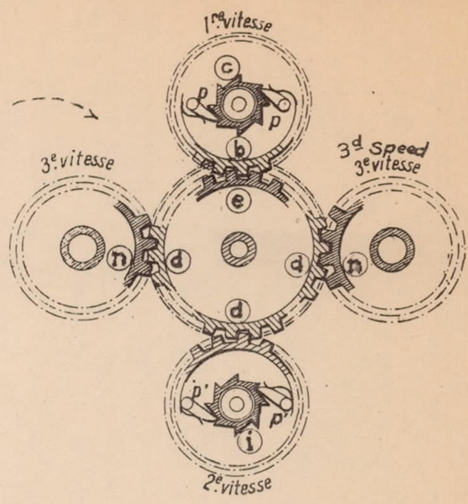
Fig. 9



.... Test of 11/25/26
12 W.E. without
supercharger
-------- Test of 11/12/30
12 W.I. with
supercharger

Fig. 10

Fig. 11 Front view of pinions



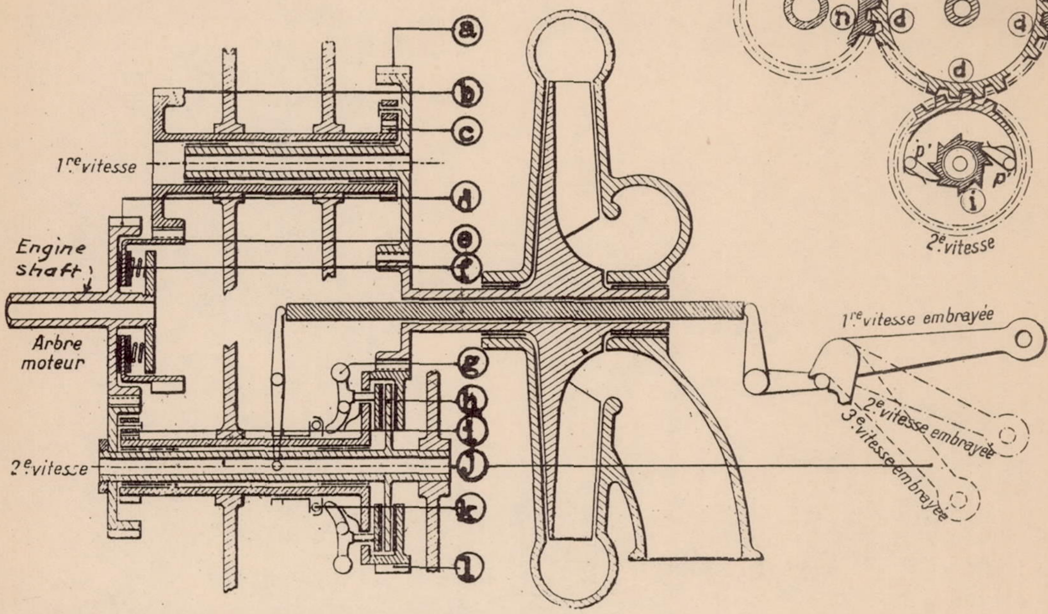


Fig. 12 Median vertical section of Farman control

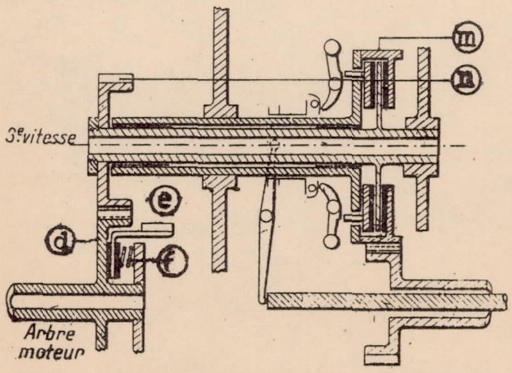


Fig. 13 Portion of median horizontal section

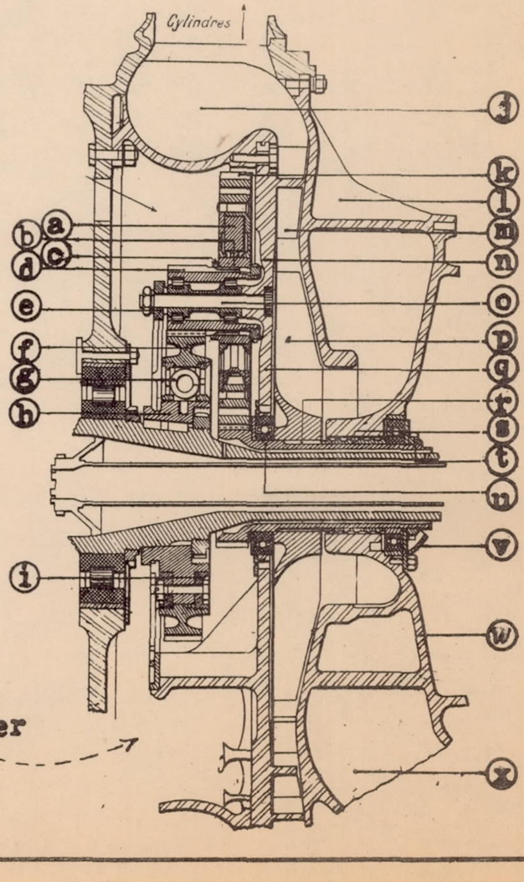


Fig. 14 Bristol supercharger

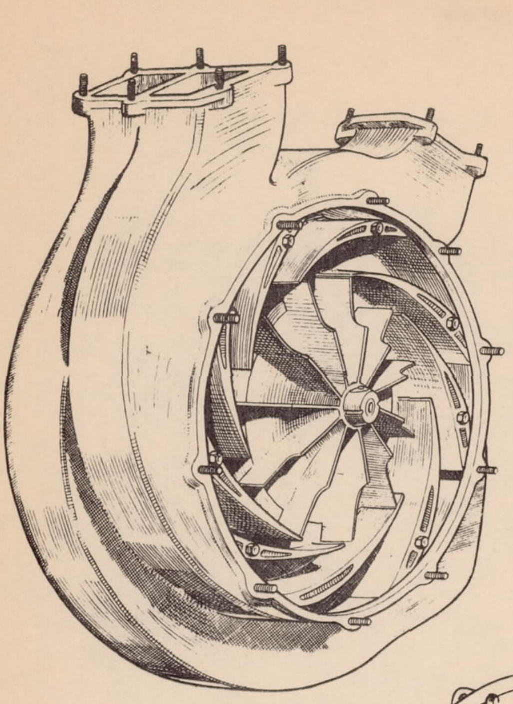


Fig. 17 a

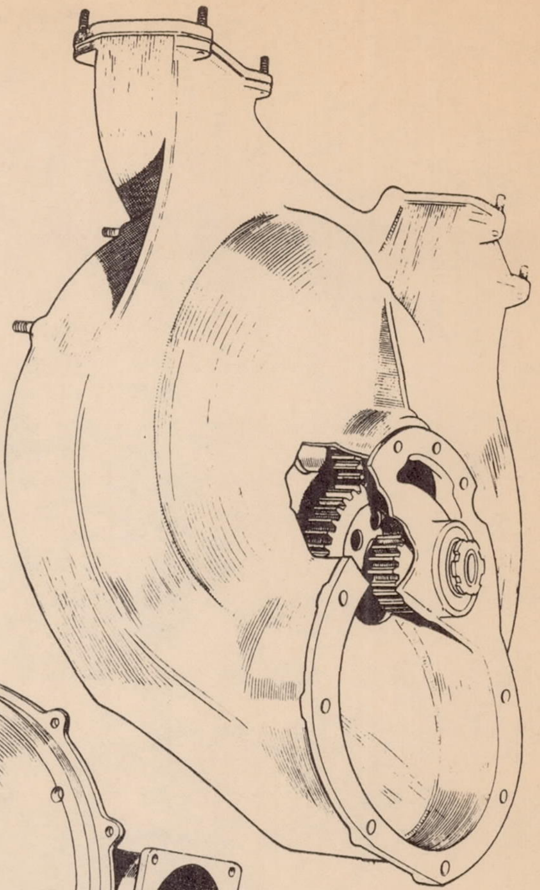


Fig. 17 c

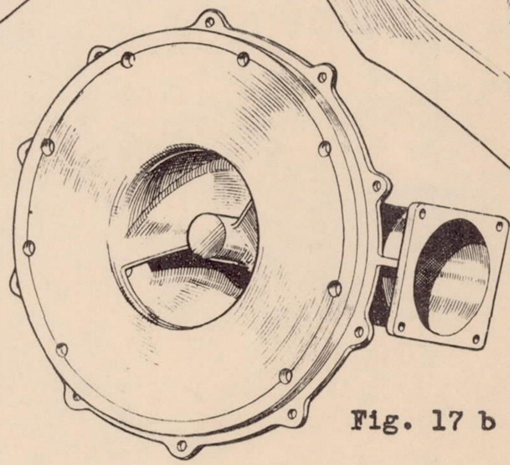


Fig. 17 b

Fig. 17 a,b,c, Supercharger of 700-850 hp.Renault engine

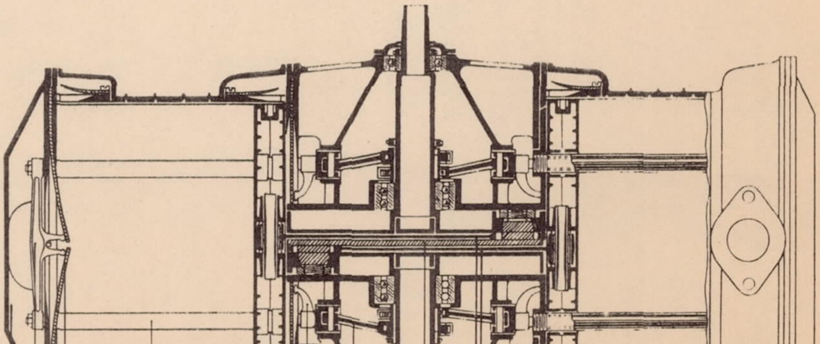


Fig. 18 Dugelay - Worthington volumetric supercharger with pistons

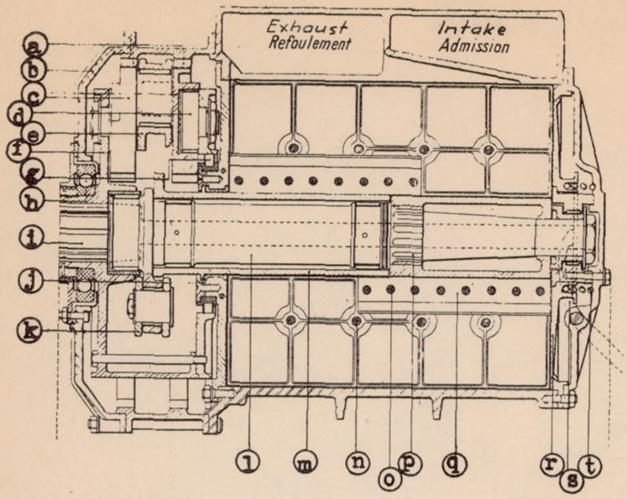


Fig. 22 P.Z. supercharger, longitudinal section

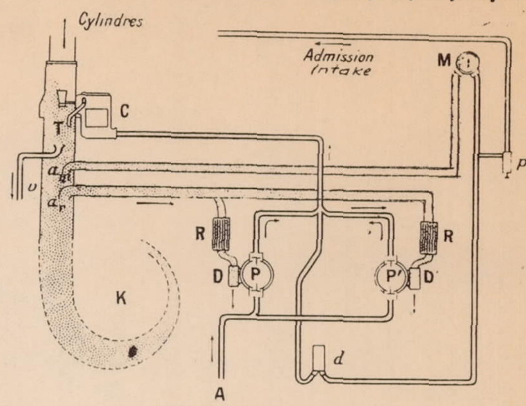


Fig. 31

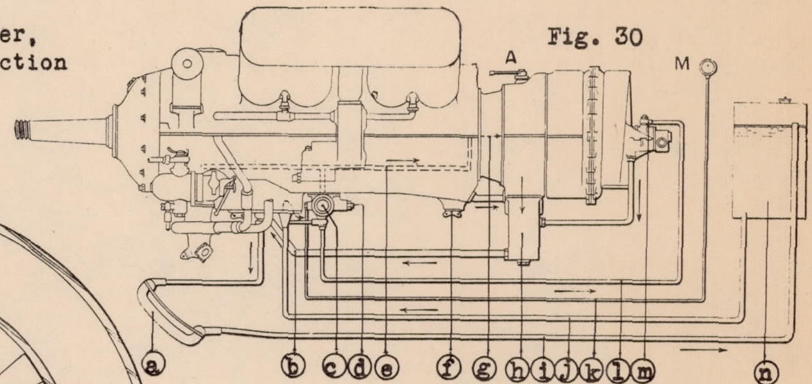


Fig.30, 31 Oil and fuel systems on Farman 12 WE engine with supercharger.

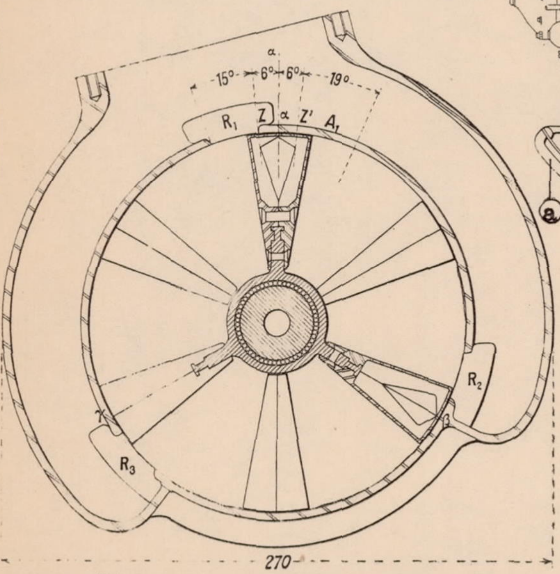


Fig. 23 P.Z. supercharger, transverse section showing two 3-blade systems

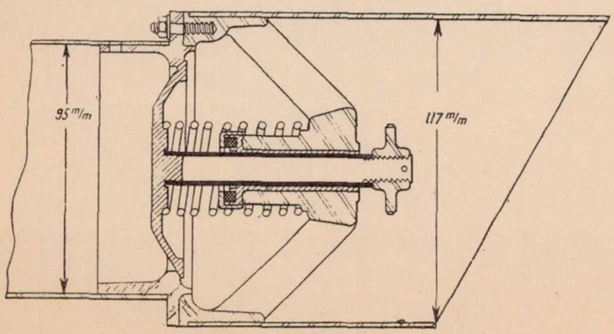


Fig. 29 Valve on manifold

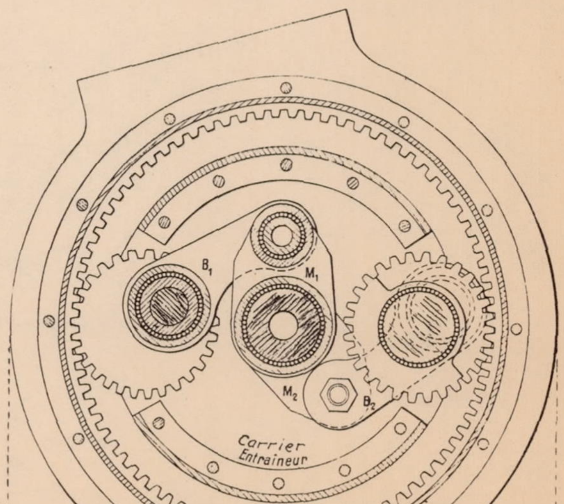
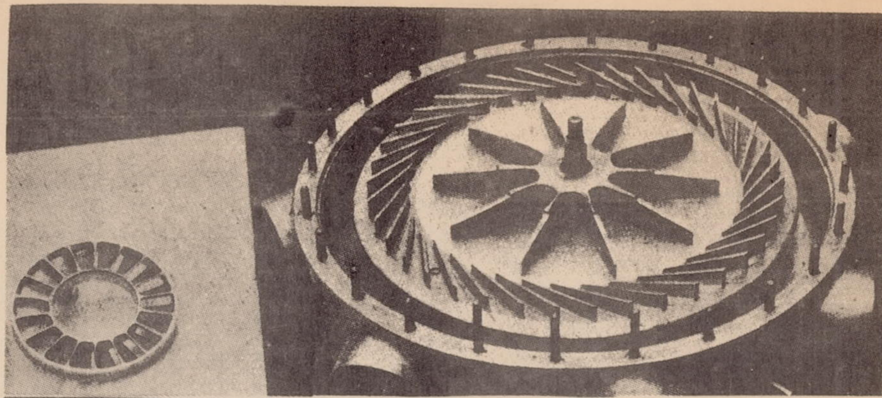
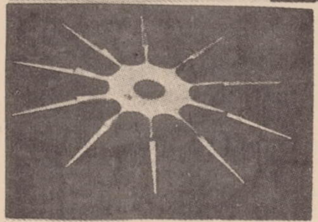


Fig. 24 P.Z .supercharger, transverse section showing driving gear of coaxial shafts





Figs. 25,26 Evolution of Armstrong-Siddeley superchargers

Fig. 25 Type I (1925)

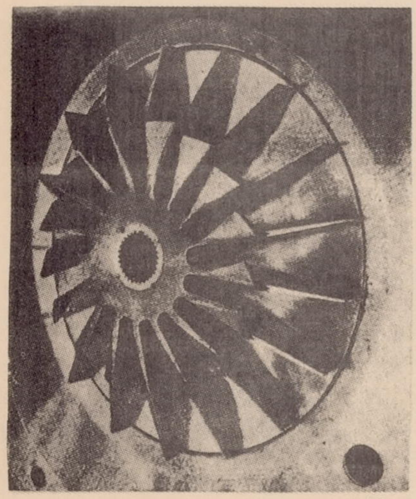


Fig. 26 Type III (1930)

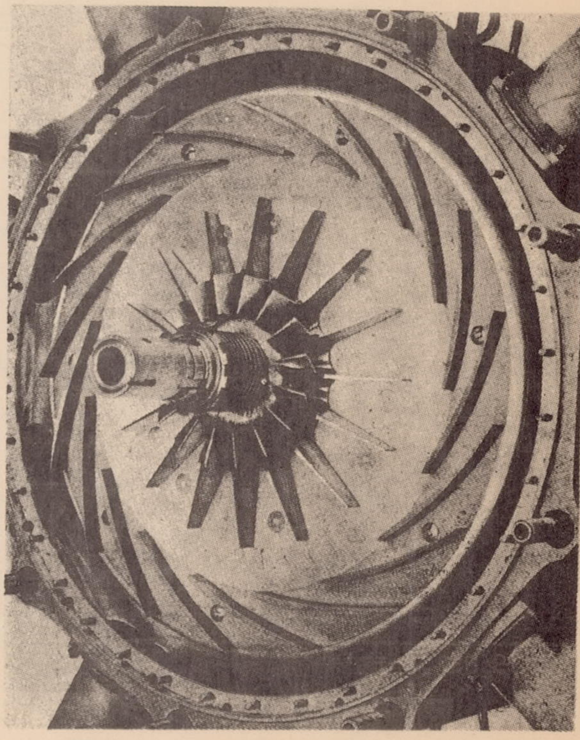


Fig. 27 Bristol supercharger (on "Jupiter" engine)

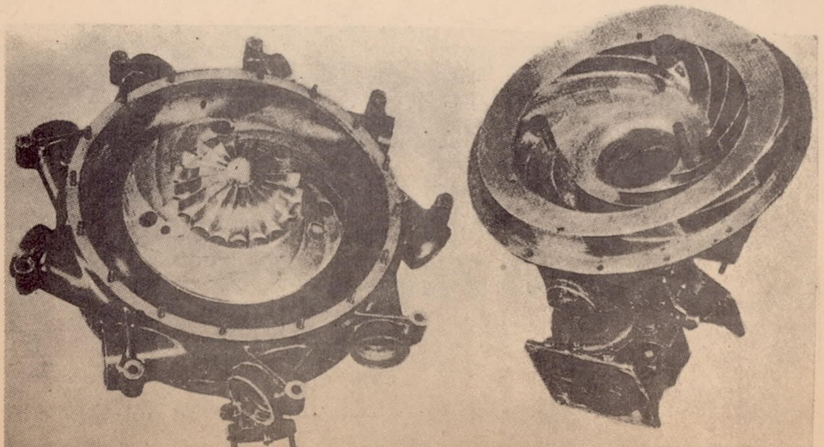


Fig. 28 Pratt & Whitney supercharger (on "Wasp" engine)